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Comparative feasibility study of fecal management methods

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ABSTRACT

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The thesis investigates the operational costs of an alternative human excreta treatment method. The reason for this study is to search for methods of saving water as well as finding solutions concerning the lack of natural phosphorus. The alternative treatment methods are composting and pyrolysis. Both treatments are evaluated on the possibility to use them for fecal material treatment regarding the price, each process will have when operating. Furthermore, other challenges like transportation and other factors are evaluated, always in the comparison of the current waste water treatment system.
This research has shown that it is unlikely that there is one process that can be applied anywhere and anytime. Thus, the composting has the smallest operational price (calculated on price per ton), the downside of it is the time the process needs, and that strict monitoring have to be done to ensure a hygienical product. In addition, the resulting compost will likely not have a good quality since the composted matter is very homogenous. Pyrolysis leads to biochar which can be sold as a fertilizer but as an energy deliverer as well.
The biggest cost factor is the transportation which can reach over 90 % of the overall price.
The results suggest that composting should be applied in smaller scale devices for villages while for bigger cities pyrolysis is the better alternative.

Diese Bachelorarbeit untersucht die Betriebskosten für eine alternative Fäkalienbehandlung. Hauptgründe hierfür sind sowohl die Möglichkeit der Trinkwassereinsparung, als auch der abnehmende Vorrat an natürlichen Phosphor. Die untersuchten alternativen Verfahren sind Kompostierung und Pyrolyse. Hierbei sind beide Verfahren hauptsächlich, aber nicht ausschließlich auf die Betriebskosten untersucht worden. So werden auch Transport und andere Faktoren evaluiert. Dabei wird immer ein Bezug auf die aktuelle Abwasserreinigung behalten.
Die Untersuchungen habe nahegelegt, dass beide Verfahren sowohl Vor- als auch Nachteile besitzen. So ist die Kompostierung die günstigere Variante (in Preis pro Tonne). Jedoch benötigt der Prozess eine lange Zeit und strenge Überwachung um ein hygienisches Produkt garantieren zu können. Außerdem eignet sich das Endprodukt der Pyrolyse auch sowohl als Dünger, als auch als Brennstoff.
Die Ausarbeitung legt jedoch offen, dass der Transport der Fäkalien der größte Kostenfaktor als der Prozess an sich ist. Die Kosten können auf über 90 % der gesamtkosten ansteigen.
Aufgrund der unterschiedlichen Vor- und Nachteile der Verfahren ist es naheliegend, dass Kompostierung in bevölkerungsgärmeren Bereichen, wie Dörfern, und die Pyrolyse in Ballungsräumen die bessere Alternative darstellt.

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GLOSSARY or ABBREVIATIONS AND TERMS (choose one or other)

cr	credit
DIN	German institute for standardization
HSH	university of applied sciences and arts Hannover
PE	population equivalent
TAMK	Tampereen ammattikorkeakoulu (Tampere University of Applied Sciences)

1 Introduction

In every developed country, fecal treatment is based on the usage of water. In general, water is used for flushing urine and human excrements in order to increase the transportability of the manure. The excrements and the urine are transported to waste water treatment plants. Almost no other treatment methods are established in the whole world, even though this system does need a lot of water (up to nine liters per flush (Burgenland, 2018)). Due to upcoming challenges like the shortage of water in developing countries, eutrophication and the lack of natural phosphorus, the question occurs, whether this process is the treatment method of the future. In fact, alternative treatments are developed and tested. One example for this is the Sweden-China Erdos Eco-Town project. This project was established in 2006 in the Mongolian area of China. Dry toilets with a separation of feces and urine have been assembled. Solidus and liquidus matters were stored separately in containers, every toilet was connected to those stores. The fecal waste was collected by a farmer who was able to utilize it on his field. The reason for the spot and the project overall was the water scarcity in the area. (Lixia & Rui, 2008)
A similar project was established in Hannover. The "Öko-Technik-Park" project started in 1995 and included 104 apartments, a church, a school and a farming area. Here, bioreactors have been established inside of the houses. Vacuum toilets have been used while the therefore required water was greywater from inside the complex. (German company for technical cooperation GmbH, 2005)

These two projects show, that alternative treatment methods are needed, and that this thesis is relevant in the present and it is not topic of the future anymore. alternative treatment methods are especially important in the regions. Additionally, the advancing lack of phosphorus leads to a major problem for the near future as well. Now, the cost calculations of the processes are applied for a village, or small town of 10 000 and a bigger one with 200 000 inhabitants. With these two scenarios, calculations of the operational costs are applied in order to get an estimation if and how an established alternative fecal treatment is doable.

1.1 Current system

In Finland as well as in Germany, over 90% of the households are connected to the canalisation. (Martin Oldenburg, 1997) Still, Finish people oftentimes live in less populated areas like secluded cabins, which have no access to the waste water infrastructure. The other households treat the human waste differently or store it until it gets picked up separately. Currently, in the canalisation infrastructure, the human excrements are flushed with up to 9 litres of water into the canalisation (in best case six litres are consumed). This waste water gets mixed with other forms of household waste water like water from showering or cleaning. All this waste water gets transported, usually driven by gravity, to waste water treatment plants. Now, the wastewater gets treated in several steps. A closer investigation of this current system will not be applied here, since the exact process is not relevant for the further work. The end products are sanitized water, Biogas (which is commonly used inside the power plant to generate energy) and dried sludge that can be used as a fertilizer or similar. The use of the biogas has become so effective over the last couple of years, that modern waste water treatment plants are self-reliant in terms of their energy demand. (Hilda Szabo, 2017)

In the year 2016, the German Government payed about 2,2 million Euros for "big building measures concerning waste-water". (federal ministry of German healthcare , 2013)

The main problem of the current waste water treatment is that the treatment plants are not good in terms of gaining the Phosphorus out of the waste water, leading to eutrophication in the following aquatic environment.

1.2 Advantages and disadvantages of a decentralized system

In general, the treatment methods can be categorized into three fields. Centralized, semi centralized and decentralized. While the current systems are based on centralized systems, this thesis also takes the use of decentralized systems into consideration. The German norm DIN 4261 part 1 – 4 (German norm) defines this concept. It specifies a framework concerning decentralized waste water treatment. This DIN limits a decentralized system to an emergence of 8 m^3/day of human waste, being equal to about 50 connected

persons. These decentralized systems have the advantage of low or even no transportation costs. An example are anaerobe reactors (biogas power plants). In a presented concept, vacuum toilets are used to transport the human wastewaters to a decentralized biogas power plant. These have the advantage, that odor emissions can be avoided better, and no extra ventilations has to be installed. Further, these toilets are better in terms of water usage since they only use about one liter. In this concept, the human wastes are combined with the bio wastes of the households. (Martin Oldenburg, 1997)
Problems with a decentralized system occur in highly populated areas, where it is more complex to build bigger collection chambers the feces could be treated or stored in. Also, the maintenance is more elaborate since the storing and treatment devices are not focused on one place but separated over a bigger area. So, maintenance personal must drive over the area as opposed to just being at the centralized treatment plant. Also, problems could occur because of different living standards in different housing spaces. In a special treatment plant where sewage sludge gets pyrolyzed in Kanton (Switzerland), sewage sludge from several treatment plants is collected. Here, cranes have to circulate the sewage sludge in order to mix it because the sludges are different, dependent on the different waste water power plants. Such mixing process of different sorts of waste is not possible in decentralized systems. So, the end product will be different as well, which is undesirable in order to proceed with these products. (City of Zürich, ERZ, 2015)

A decentralized system allows the possibility to test different methods, without taking high investment risks. So, installing smaller scale treatment devices is, in comparison to a centralized one, much cheaper. This allows creating test subjects. This way, a comparison between the different methods can be created, leading to a better engineering progress, because only if we try different methods, we can achieve the knowledge which is the best in practice. In addition, a decentralized system may lead to an increase of the feeling of responsibility for the people. (Fischer, 2001) Some people are disregardful concerning waste separation. This leads to problems at the treatment facilities. If these treatment facilities are closer to the producer of the waste and the catchment area is not thousands but only a few peoples, people might start thinking more about the system.

1.3 Pyrolysis

The process of pyrolysis means the drying and degassing of biological materials under exclusion of oxygen. It is an endothermic process that does have an exotherm part. In the range from 100 – 200 as well as from 400 – 600 centigrade it is endotherm, while only in the range from 200 – 400 centigrade it is an exotherm process. So, in the major part of the process, energy must be fed to keep the process going. (Maaß, 2015)
The overall process can be classified by temperature as well as by duration. A classification of the process by temperature leads to the categories of high- mid- and low-temperature pyrolysis. A classification concerning the duration is more significantly, since the outcome of the process depends on this. Here, the duration depends on the temperature as well (Maaß, 2015). As apparent in the following table (

Table 1), the different processes lead to different compositions.

Table 1 non-substance specific composition (in mass percent referring to the dry sub-

	Conditions	**Liquid**	**Char**	**Gas**
Slow pyrolysis	Low temp., very long residence time	30 %	35%	35%
Mild pyrolysis	Low temperature	-	70-90 %	-
Fast pyrolysis	Moderate temp, short residence	75 %	12 %	13%
Gasification	High temperature, long residence time	5%	10%	85%

stance) of different sorts of pyrolysis (Mayhead, 2011)

This table emphasises that the composition of gaseous, liquidous and solid matter can be achieved with different sorts of pyrolysis. Which of these different compounds are preferable depends on the application. Solid and liquidous products can be used as fuels. Therefore, they are suitable as saleable products. On the other hand, the resulting gas can be burned immediately. This heat is normally used for heating up the prevenient reactor. How such process can be realized is represented in Figure 1.

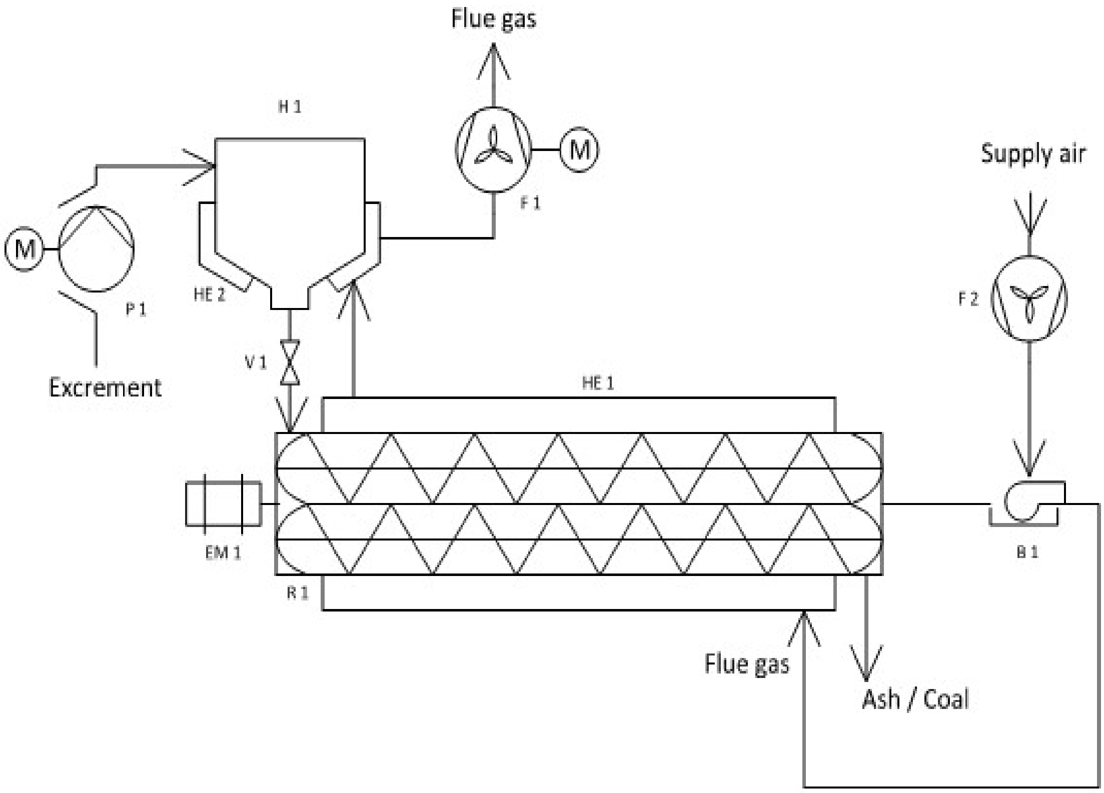

Figure 1 flow diagram of a sewage reactor

To increase the understanding of the overall pyrolyzing process, Figure 1 pictures a flow diagram of a pyrolysis system. Please note that this is not the system described in the further thesis, but it corresponds to the described process. The pictured process was part of another project work, realised last semester. Further information can be askes from Eeva-Liisa Viskaari from Tamk. In the process from the TAMK, the excrements are fed, using a pump into a hopper where the mass gets dried. Afterwards the dried mass gets fed via a valve into the reactor where it is pyrolyzed. In the real process, the biological mass is pyrolyzed for six minutes inside the reactor. The occurred gas gets ventilated into the cyclone while the resulting biological coal is charged with water and then stored. The exhaust gas gets burned in the burn chamber, cleaned in another cyclone, and then used for heating the reactor. Afterwards the use of the remaining thermal energy depends on the application. In this case it is used in a heat exchanger to heat up water and later for the drying of the raw material (greenlife ressources GmbH, 2018). A data sheet for this reactor can be seen in chapter 3.

1.4 Composting

In principle, composting fecal matters does not differ from composting other biological matters. An equivalation of the process is illustrated in Figure 2. Composting means the metamorphosis of organic matters into other, less pathogenic materials. So, the aim is increasing the hygiene of biological waste. (Jenkins, 1999)

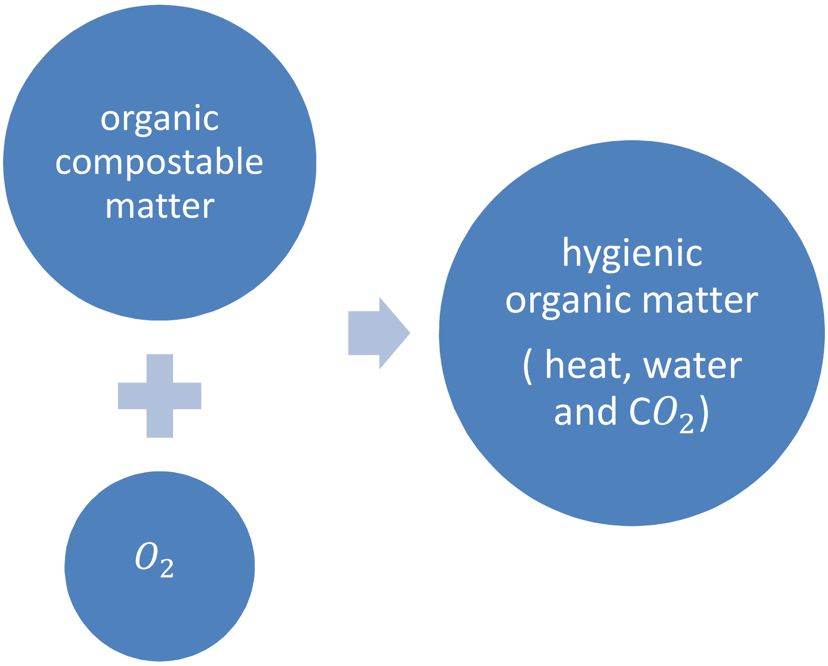

Figure 2 schematic figure of transubstantiation in the composting process

In general, the composting process can be divided in two phases. Active phase and curing phase. In the active phase, the population of thermophilic bacteria increases rapidly together with the temperature inside the compost pile. Within 24-72 hours, the temperature inside the pile increases up to between 55 and 65 °C. In this Phase, most of the pathogenic compound are destroyed. It lasts several weeks in which the operator of the compost must make sure, that enough oxygen is added to the compost pile. This can be secured by turning the pile or by ensuring an airflow through the pile. In addition, an observation and, if necessary, adaption of the moisture as well as nitrogen and carbon (C:N ratio) is necessary. (Jenkins, 1999)

After some weeks, the temperature decreases and the second phase of composting, the curing phase starts. When the phase begins, the compost can be stockpiled because of a change in the bacterial system, which leads to a lower oxygen demand. Here, the thermophilic bacteria population decreases, and mesophilic bacteria proliferate. The duration of the phase is dependent of the preceding monitoring of humidity and oxygen supply. A lack of accuracy concerning these values in the active phase leads to longer durations of the second phase. The duration of the curing can be estimated to one to four months, mainly dependent on the demanded quality. (Jenkins, 1999)

Also, the duration of the process depends on the sort of composting. Here, the process is defined to be finished when the matter is hygienic. This depends mainly on the temperature. When the temperature is under 10 centigrade, enteroviruses (most aggressive virus) can survive up to 170 days in a pH-environment of 7,5. In warmer environments, they survive up to 110 days. Besides, the temperature, the pH is also a factor, which has a smaller influent. Thereby, a pH of 5,0 can shorten the days of survival for 20 days. (Jenkins, 1999)

1.4.1 Different procedure possibilities

One of the main challenge of the composting process is the aeration of the pile to spend oxygen that is consumed by the aerobe bacteria. Keeping the pile aerobic avoids odors as well. Aeration is mainly done by three methods:

1. Turning of the Pile
2. Aeration via ventilation
3. Use of coarse material

The third method is mainly applicable in small scale composting. Here, coarse materials like straw or hay are mixed into the pile. Their structure opens cavities inside the pile. This enables an air-flow through the pile, which again leads to an aeration of the composting materials. (Jenkins, 1999)

In bigger scale composts the other two possibilities are applied. Here, the use of a ventilation system in general creates a more constant aeration to increase the quality of the product. A downside of this process is that it is very expensive since the ventilation as well as the necessary measure devices consume a lot of energy.

Turning the pile has more functions than just aerating. It mixes the pile. That way every part of the pile gets the heat that develop inside a compost. This ensures that pathogens do not survive, and the product is hygienically safe. Also, turning the compost homogenizes the product making it better for further use. At last, turning also increases the compost process.

So, to find out the suitable process, the demanded quality and the prices are most important. (Jenkins, 1999)

1.4.2 Advantages and disadvantages of the composting process

Advantages:

Simplicity:

The major advantage of this process is the simplicity. Controlling this process does not requires a lot of energy or further attention, if no ventilation or emission control has to be used. When initiating the process, experiences must be made to understand the process better and to find perfect conditions for the manure composting. Afterwards, the process can be applied easily. This advantage is limited on small scale devices because, as mentioned, in bigger scale a high-tech way of composting hast to be chosen (Brington, 1998).

Saleable product:

The selection of the higher-class composting results in higher class product, which is saleable. This increases the actual costs of the process since money that must be invested for controlling and aeration devices can be gained by selling the soil. These costs could be regained by selling the product (Brington, 1998).

Disadvantages:

Winter:

Composting is dependent from surrounding conditions. Especially in winter times, the composting can come to a stop because it is too cold and not moist enough. This occurs, when the composting pile is too small. If the compost pile is at least 3,5 meters high and 3,5 meters wide, the composting process can be pursued. Still leading to a restriction of the functionality of the composting. So, due to the duration and the temperatures of Finnish winters, this could lead to a demand of a heated environment (Brington, 1998).

Location decision:

The selection of a suitable area for composting is one of the most important and difficult things. At first, there has to be a big area where these composting fields can be established. These fields should be well connected to the infrastructure, but at the same, not densely populated nor cultivated. Otherwise problems with public administration have to be expected. In addition, water protection areas can be a limiting factor. It has to be made sure that no wells are in the direction of the groundwater flow since contaminants and pollutants can get to the groundwater. If no suitable place comes up, several actions in order to prevent the contaminants from reaching the ground water must be established. These actions increase the asset costs even more (Brington, 1998).

Monoculture:
In normal composts, many different sorts of biological waste are combined. In this case, fecal will be a huge majority. Now, it is questionable in how far the composting process will be affected by this. If this monocultural environment limits the composting process too strongly, other materials, like bio waste or special plants, have to be collected separately and added to the piles (Cooperband, 2002).

Laboratory:
When using composts, oftentimes laboratories have to be employed as a controller. That way, it can be assured that all pathogens and pollutants are eliminated from the pile. Generally, one investigation of the important factors costs about 350 € (Viskaari, 2018).

2 Scope of the work

The aim of this thesis is to do a feasibility study and cost-efficiency analysis of source separated fecal matter compared to the current wastewater treatment systems.
This concept will be applied on a hypothetic case study, where feasibility and cost-efficiency of current wastewater treatment system is compared to alternative systems where manure and urine are collected and treated separately. The acquisition costs to change the existing, water using system into the new system will not be considered. Focus of the thesis is to find the operating and maintenance costs of the new system and compare these to the current ones. These will be considered for different sizes of cities in a range from a very smaller (about 10 000 inhabitants), to bigger (200 000 inhabitants) cities. When necessary in order to collect necessary data, Hannover (Germany) will be used for scale. Here, the cost calculations will primarily be exercised on German standards. Nevertheless, the gained knowledges will be applied to Finnish standards, as far as this is possible. The client is Tampere University of Applied Sciences (TAMK).
The initial situation will be that urine and feces (with organic matter like toilet paper) are collected separately. Several treatment possibilities will be pursued and an economic analysis as well as a feasibility study will be exercised. The regarded processes are composting and pyrolyzing.

3 Material and methods

3.1 Materials

In order to do the feasibility and cost-efficiency study we used data from various sources that are presented below. Here, only those tables and values are mentioned that have not been calculated by my-self but have been taken from the named sources.

3.1.1 Current system

In year 2003, a study about the costs of waste water treatment plants was done. The costs per year and PE are presented in Figure 3.

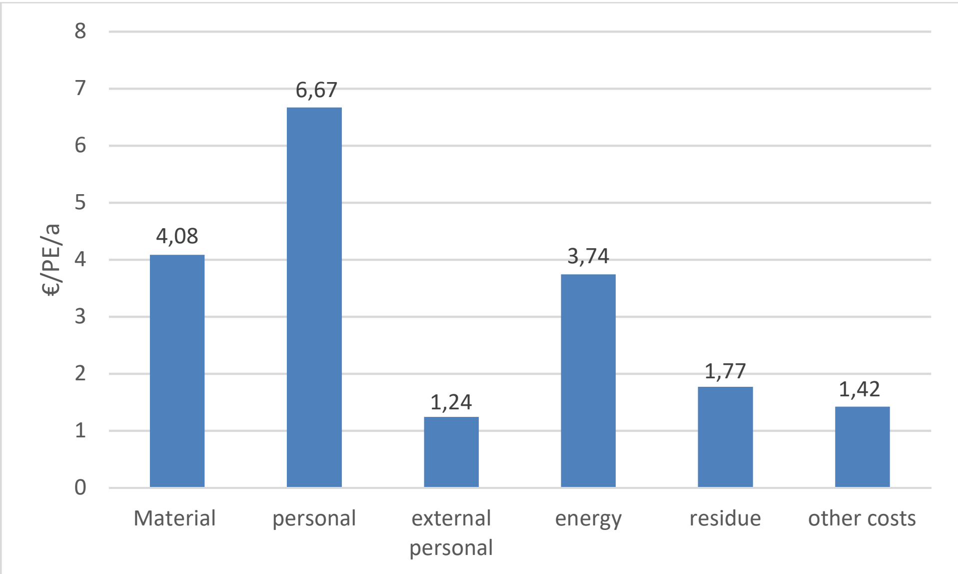

Figure 3 Price per PE and year distributed to different parts of a waste water treatment plant, German taxes included (Dürr, 2014)

The graph shows the costs per PE and year (ordinate), categorized on the causes (abscissa). The sum of the costs are 18,92 €/PE/year. It gets clear that the biggest cost factor is the personal sector with 6,67 €/PE/year. The least expensive section is the external personal sector.

Further, Dürr (2014) divides the costs based on the source of costs:

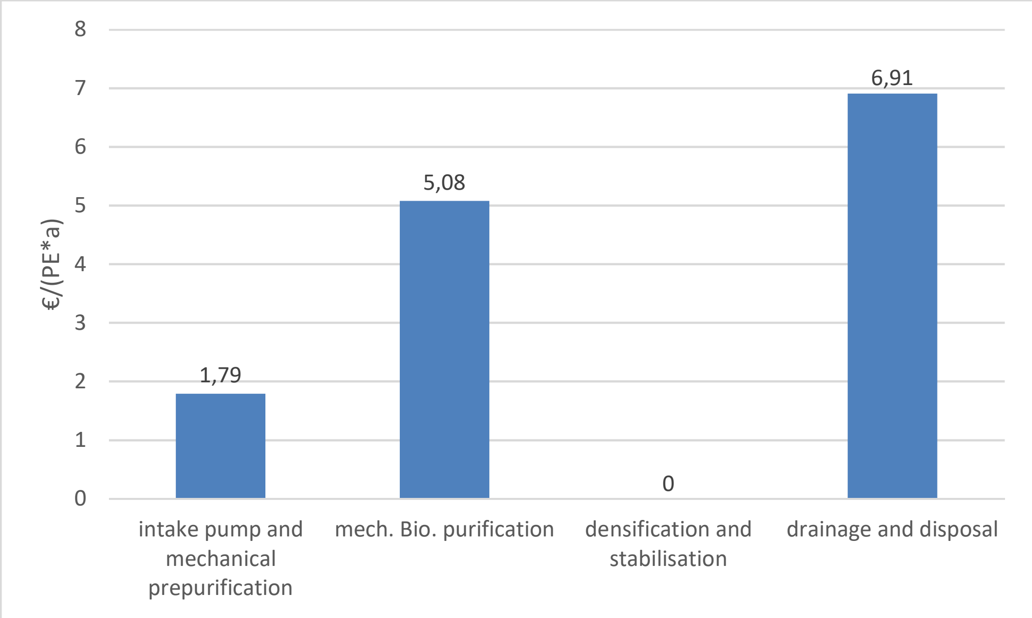

Figure 4 cost allocations on the different treatment processes in a waste water treatment plants

The graph shows the costs per PE and year (ordinate), categorized on the process (abscissa). Here, the most expensive process is dedicated to drainage and disposal. The intake pumps are responsible for the transportation of the waste water into the treatment plant.

3.1.2 Pyrolysis

The technical characteristics of the pyrolysis reactor that is the main part of the pyrolysis process presented in chapter 1.4 are given in Table 3.

Table 2 data sheet of pictured reactor, taken from (greenlife ressources GmbH, 2018), translated from German into English

Characteristic	Value
Capacity	4000 t dried sewage sludge
Disposal of sewage sludges per plant	Up to 50. 000 PEs
Biochar production	500 t/a (dependent on raw material)
Nominal fuel capacity	500 kW
Maximum operational limits	Calorific value > 6 MJ/kg; humidity < 50%
Thermal output	150 kW exhaust-gas heat
Power input	7,5 kW (el)
Dimensions	8m x 2,5m x 2,5m

The German ministry of environment published a beneficiary study of a pyrolysis reactor from the Company PYREG. Here, the reactor is very similar to the one pictured in Figure 1. The difference is that in the PYREG reactor, vegetable waste is pyrolyzed instead of fecal matter.

Table 3 Beneficiary analysis of a PYREG installation, based on the data from: (ministry of environment, 2009)

Investment	500 kW PYREG installation			**300 000**	**€**
Costs-capital				**28 080**	**€/a**
	15 years write-off; 5% interests	28 080	€/a		
Operational costs				**13 000**	**€/a**
	Insurance	3 000	€/a		
	Maintenance (0,5 h/day)	5 000	€/a		
	Repairs	5 000	€/a		
Costs for consumption				**2 100**	**€/a**
	Electrical cost: 0,15 €/kWh, 8000 h/a, P=1,5 kW	1 800	€/a		
	Costs for gas 333 kg / a propane	300	€/a		
Overall costs				**43 200**	**€/a**
Earnings				**117 400**	**€/a**
	Biochar- earning 340 t/a, 150 €/t	51 000	€/a		
	Heat energy 166 kW, 0,05 €/kWh, 8000 h/a	66 400			
Annual balance				**+ 74 220**	**€/a**

3.1.3 Composting

The following Table 4 is referring to composting and will be used to estimate the expenditure for the composting process. Here, cost estimations have been done by Jenkins and by Brington (1998). The results differ slightly so a median value was calcultaed.

Table 4 Cost per (wet) ton for composting process, values in dollar taken as a combination of (Brington, 1998) and (Jenkins, 1999); exchange rate of 1,2366 Dollars/Euro (stand: 14.03.2018, (wallstreet online, 2018)).

turns of pile	Price per wet ton (in €; American taxes included)
no turn	2,426
Bucket turn	4,85
once, every two weeks	10,51
twice a week	36,39

Further information about operational costs of the composting process are pictured in Table 5. These estimations refer to bio waste in general and not specifically to fecal matter.

Table 5 Cost estimation for an indoor composting process, total costs are rounded (Epstein, 2011)

Source of cost	Price per year	Price per ton (25 000 ton)	Included costs
Labor	332 920 €	13,32 €	Supervisor (1) Operators (4) Laborites (2)
Business management costs	47 000 €	1,88 €	Legal, regulatory, consulting Administration and billing Association, public relation, outreach Training, safety Marketing, feedstock, and product

Processing	1 484 505 €	59,38 €	Electrics (incl. heating and ventilation) Emission treatment Water and sewer Natural gas Maintenance Grounds Operating consumables Laboratories and misc. Miscellaneous Management and operating fees (20%) Contingency (5%)
Total costs	**1 860 000 €**	**75,000 €**	

3.1.4 Transportation

To estimate the cost for the transportation, the values for biological waste will be taken as a base. Table 6 shows exemplary prices for different sizes of waste bins.

Table 6 costs for bio waste collection for collection every 14 days (city of Kiel, 2018)

Size	Price per year	Price / litre [€/(litre*year)
40 l-bio waste bin	58,92 €/year	1,473
80 l-bio waste bin	68,76 €/year	0,8595
120 l bio waste bin	78,60 €/year	0,655
240 l- bio waste bin	116,16 €/year	0,484

3.1.5 Price for drinking water

The thesis also deals with the likely development of the price for drinking water. Therefore, two trendline have been taken in the estimation (Figure 5and Figure 6).

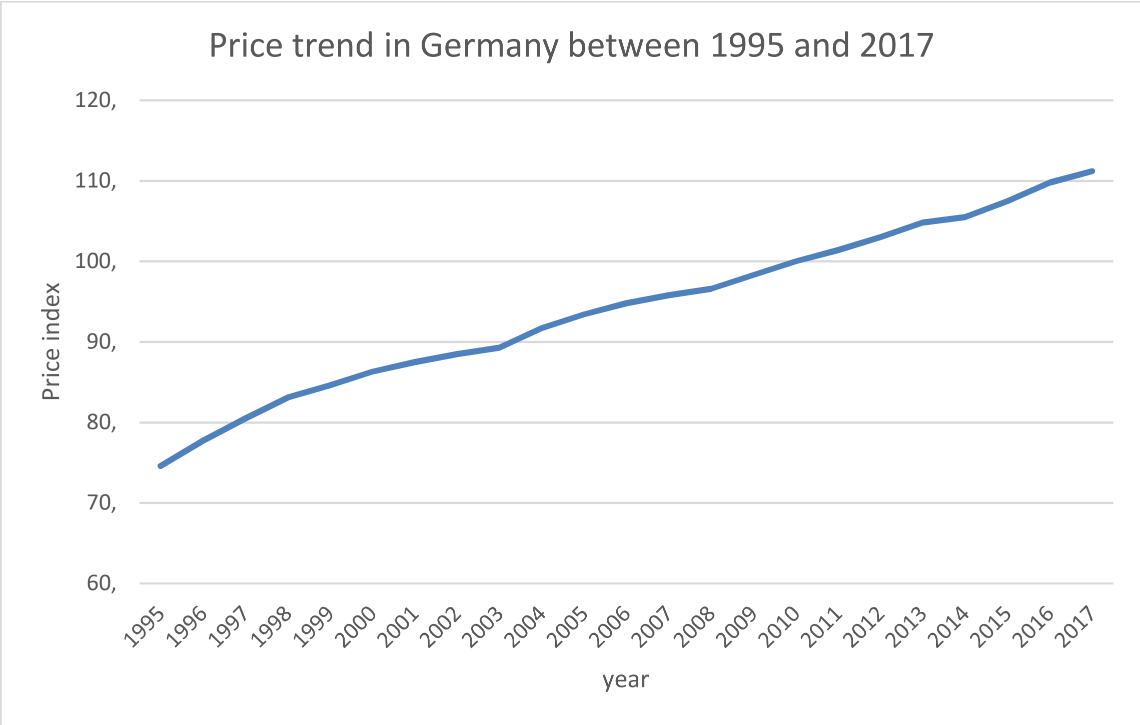

Figure 5 water supply cost index (ordinate) for in Germany for the years 1995 to 2017 (abscissa) (federal statistical office Germany, 2018). The index is defined, that the value 100 rep-resents the price for drinking water in 2010.

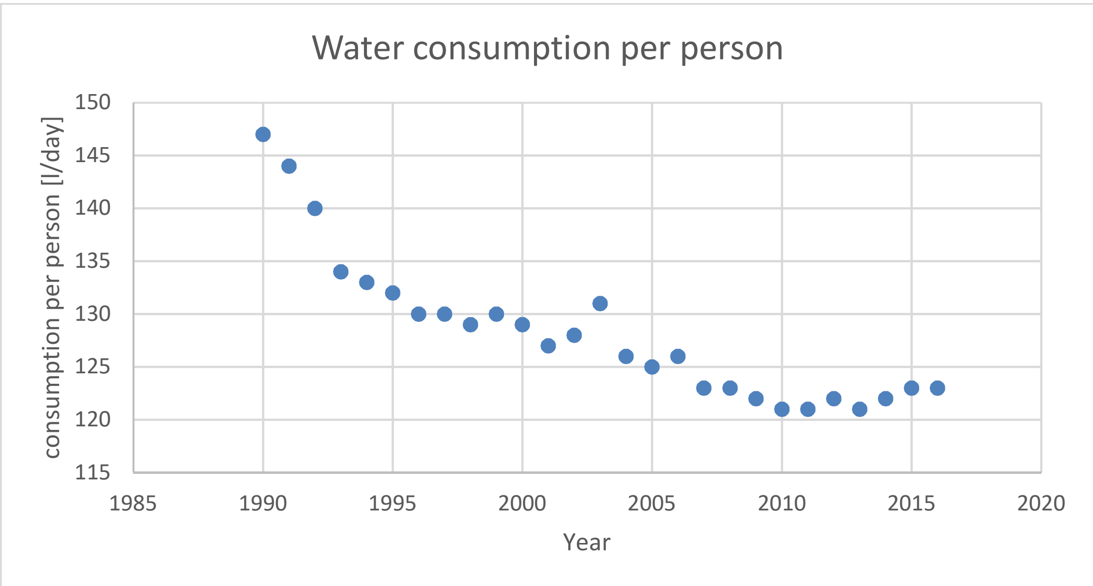

Figure 6 Water consumption per person and day in litre in Germany (ordinate) in relation to the years 1990 to 2016 (abscissa) (federal statistical office Germany, 2018).

3.2 Methods

To evaluate the treatment methods, a set of assessment criteria are presented below. These will be the main factors to be investigated in the following thesis. The criteria are presented in order of their importance in this study.

3.2.1 Assessment criteria for treatment methods

The following assessment criteria are taken into consideration.

1. Feasibility
   The most important question is, whether the treatment method is generally applicable for treating fecal matters or not. Here, limitations of a process are mentioned but until the general success of the process is considered possible, the feasibility is accepted. Also, legislation must be taken into consideration when assessing the process feasibility.

2. Hygiene
   To be feasible and to be accepted by governments, the hygiene of the product must always be secured. Every part of the processed matter must be free of pathogens, bacteria and other pollutants.

3. Costs
   The cost analysis has major importance as well. These costs are related to the process itself, but also to the necessary work around the process. Here, maintenance and other further operational costs are included.

4. Reliability
   It is also important for the process to be reliable. Neither temperature nor weather or other external factors should have an impact. This way a constant-quality product is ensured.

5. Odor emission

   In processing the fecal matter, odor emissions have to be minimized since the public is sensitive to odors. Also, legislation regulates the allowed values for the odor emissions.

3.2.2 Assesment criteria for transportation

The assessment criteria for the success or fail of a storing and collecting method are presented below.

1. Reliability

When a transportation or storing method is taken into consideration, the highest importance lays on the methods' reliability. If the process is not declared as reliable, this leads to an elimination of the method since it is of highest importance to have a trustworthy system, without the risk of many failures during the process.

2. Costs

Estimating the costs of the transportation or storing method is again a major part. Goal is to make a good estimation of the whole faecal treatment system. The main focus is on the energy necessary for the transportation.

3. Sustainability

Different transportation or storing methods can have different impacts on the environment. These impacts will be taken into consideration here since they could lead to other costs, that occur in the future like pollution treatment of air, soil or water.

4. Public respond

It can be assumed that different transportation or storing methods will lead to different responses from the public. An estimation of possible critics, the public could come up with will be done.

4 Results

4.1 Emergence of manure in both scenarios

Averagely, every adult person defecates 0,2 kg of manure per day (Konradshöhe Gmbh, 2018). So, in the two different scenarios of 10.000 and 200.000 peoples, the following amounts of manure emerge per year:

$$m_{200\,000} = 0{,}2\frac{kg}{person * day} * 200\,000\,Persons * \frac{1\,ton}{1000\,kg} = \frac{\boldsymbol{40tons}}{\boldsymbol{day}}$$
$$= \mathbf{14\,600}\frac{\boldsymbol{tons}}{\boldsymbol{year}}$$

$$m_{10\,000} = 0{,}2\frac{kg}{person * day} * 10\,000\,Persons * \frac{1\,ton}{1000\,kg} = \mathbf{2}\frac{\boldsymbol{tons}}{\boldsymbol{day}} = \mathbf{730}\frac{\boldsymbol{tons}}{\boldsymbol{year}}$$

4.2 Current system

4.2.1 Water consumption with associated costs of the current system

The water consumption for using the toilet for an average adult can be approximated to 40 l/day((Burgenland, 2018). In Germany, two invoice values have to be considered. In Hannover, receiving 1 m³ of drinking water costs 1,58 €/m³. In addition, 1,72 €/m³ are charged for leading wastewater into the canalisation (Urban drainage of the state capital Hannover, 2018). With these data, the annual price of the water consumption of a toilet can be determined:

$$Price_{water} = \frac{Price}{volume} * \frac{volume}{day} * \frac{days}{year} = (1{,}58 + 1{,}72)\frac{€}{m^3} * \frac{40}{1000}\frac{m^3}{day} * 365\frac{day}{year}$$
$$= \mathbf{48,18}\ \frac{€}{\boldsymbol{year}}$$

This means, that (in average) every adult person in Germany pays 48,18 € per year for flushing.

4.2.2 Energy consumption and costs

The existing wastewater treatment plants in Hannover published a data sheet in the beginning of 2017. Regarding those, both waste water treatment plants have a combined energy consumption of 26,48 GWh/year. 58% of this energy can be generated internally, leading to a gap of 11,12 GWh/year. Combined, both have a PE of 1,25 million (Hannover, 2017). The price per kWh in Germany for industrial customers is about 15 cents (ministry of environment, 2009) . So, the needed money can be calculated as follows:

$$price_{energy} = consumption * \frac{price}{consumed\ energy} = 11{,}12 * 10^6 \frac{kWh}{year} * 0{,}15 \frac{€}{kWh} = \mathbf{1{,}668\ \frac{mio\ €}{year}}.$$

As mentioned, the respective treatment plants have a PE of 1,25 million. Assuming that price is separated on the PE value, every person has to pay:

$$Price\ _{Energy,Hannover} = \frac{1{,}668}{1{,}25} \frac{mio\ €}{year*mio\ PE} = 1{,}33\ \frac{€}{year*PE}$$

The results from Dürr (2014) conclude an energy price of 3,74 €/year/PE. This value is a median value for several waste water treatment plants. This may explain the difference. Here the complete operational costs are 18,92 €/year/PE. The further cost allocation of the whole treatment process can be seen in Figure 4.

Adding the costs for the water to this figure, the overall operational cost for one PE equals to:

$$Costs_{Waste\ water\ treatment\ plants} = costs_{operating} + costs_{water}$$
$$= 18{,}92 \frac{€}{PE * year} + 48{,}18 \frac{€}{PE * year} = 67{,}1 \frac{€}{PE * year}$$

4.3 Pyrolysis

The costs that have been estimated for the PYREG reactor are pictured in Table 3. They can be used as a base for the following calculations. The most important information is that 7,5 kW electrical power is needed for treating the human waste of 50 000 peoples. To get a more realistic price, the price for electrical power for industrial customers will be applied. So, under the presumption that the device runs about 8000 h/year (typical figure for constructing a consecutively running device, when assuming that the process will run all year around (8760h) with stops for maintenance and repair) the energy costs for this device can be calculated as follows:

$$Price_{\ energy,absolute} = Power * time * energyprice$$
$$= 7{,}5\ kW * 8000 \frac{h}{year} * 0{,}15 \frac{€}{kWh} = \mathbf{9000\ €/year}$$

The operational costs can be expected to the same as in the PYREG installation, since the overall structure is similar. So, the operational costs can be calculated accordingly:

$$Operational\ costs = Costs_{insurance} + Costs_{Maintenance} + Costs_{Repairs}$$
$$= 3\ 000\ \frac{€}{year} + 5\ 000\ \frac{€}{year} + 5\ 000 \frac{€}{year} = \mathbf{13\ 000} \frac{\mathbf{€}}{\mathbf{year}}$$

Additionally, a wheel loader is needed. Regarding Kendzia (2016), the price for a wheel loader with driver included, is about 60,50 €/hour. This information allows the following calculation:

$$price_{machinery,absolue} = \frac{price}{hour} * hours = 60{,}5 \frac{€}{h} * 8\ 000 \frac{h}{year} = \mathbf{484\ 000} \frac{\mathbf{€}}{\mathbf{year}}$$

With these values, the total operational costs can be calculated (Table 7):

Table 7 overview of the operational costs per year for using a pyrolysis reactor with German taxes of 19 % included

Cost categorize	price
Energy	9 000 €/year
operational	13 000 €/year
Machines	484 000 €/year
Total	**506 000 €/year**

Under the permission, that these costs can be divided per PE and the it is for 50.000 peoples, every producer of one PE would have to pay:

$$\frac{Price}{PE} = \frac{506\ 000\ €/year}{50\ 000\ PE} = \mathbf{10{,}12} \frac{\mathbf{€}}{\mathbf{year * PE}}$$

Now this figure is used for calculating the prices in the two scenarios:

$$price_{200\,000} = 10{,}12 \frac{€}{year * PE} * 200\,000\,PE = \mathbf{2,042}\ \frac{\boldsymbol{million}\ €}{\boldsymbol{year}}$$

$$price_{10\,000} = 10{,}12 \frac{€}{year * PE} * 10\,000\,PE = \mathbf{101\,000}\ \frac{€}{\boldsymbol{year}}$$

Because of the pyrolyzing process, a hygienical product is ensured. There have not been any reports concerning odor emissions. Still, odors can be expected in the exhaust air and the storing place. Here, using a closed store would find a remedy. Security devices concerning explosion, like devices to sort foreign matters out, might be necessary as well. Also, the reliability of the process is not likely to be bad since the process is rather simple and does not use many devices with a high failing rate.

4.4 Composting

The cost assumptions pictured in Table 4 are based on small scale applications. So, they only include material costs for the composting and the rent for smaller devices to turn the pile. To ensure a hygienic product of the whole mass and over the whole year, bucket turn has to be applied when the process is not located inside a hall. Otherwise the cold would make a run of the process impossible. So, the costs of this process are estimated to 4,85 €/wet ton. When taking an amount of 200.000 peoples, the following amount of faeces will be composted.

The costs can be calculated:

$$costs_{200\,000,outside} = 40 \frac{ton_{wet}}{day} * 4{,}85 \frac{€}{ton_{wet}} = \mathbf{194} \frac{€}{\boldsymbol{day}} = \mathbf{70\,810} \frac{€}{\boldsymbol{year}}$$

In the second scenario, the following price occurs:

$$costs_{10\,000,outside} = 2 \frac{ton_{wet}}{day} * 4{,}85 \frac{€}{ton_{wet}} = \mathbf{9,16} \frac{€}{\boldsymbol{day}} = \mathbf{3340} \frac{€}{\boldsymbol{year}}$$

Concerning the source (Martin Kranert, 2004) a minimum of 40 % of the mass of the excrements are dry mass. So, out of these 40 tons wet mass for 200.000 peoples, about 16 tons of dry mass will be left after being composted (for 10.000 peoples, 0,8 tons occur). It can be assumed here, that farmers or other people will take the compost for free. Similar procedure can be seen in modern waste water treatment plants concerning the composted sewage sludge.

These calculations are only valid, if no further devices for aeration, heating, or emission control are applied, which is only possible for smaller scale piles. In bigger scale devices there is no real alternative to proceeding inside a hall. If so, the pure composting costs can be calculated with the cheapest method from Table 4 (Epstein, 2011). In this case, the price per wet ton is 2,426 €.

$$costs_{composting,cheapest,200\,000} = 40\,\frac{ton_{wet}}{day} * 2{,}426\,\frac{€}{ton_{wet}} = \mathbf{97}\,\frac{\mathbf{€}}{\boldsymbol{day}}$$

$$= \mathbf{35\,420}\,\frac{\mathbf{€}}{\boldsymbol{year}}$$

$$costs_{composting,cheapest,10\,000} = 2\,\frac{ton_{wet}}{day} * 2{,}426\,\frac{€}{ton_{wet}} = \mathbf{4,852}\,\frac{\mathbf{€}}{\boldsymbol{day}}$$

$$= \mathbf{1\,771}\,\frac{\mathbf{€}}{\boldsymbol{year}}$$

The composting costs per person are:

$$0{,}2\,\frac{kg}{day * PE} * \frac{1\,ton}{1000\,kg} * 365\,\frac{days}{year} * 2{,}426\,\frac{€}{ton} = \mathbf{0,177}\,\frac{\mathbf{€}}{\boldsymbol{year * PE}}$$

Regarding these calculations, it has to be taken into account, that none of the used estimations refer directly to the composting of fecal matter. Still the numbers do give an estimation, since they refer on different material (green-waste and sewage sludge).

Because of hygienic concerns and emission legislation, the compost, in most places, must be proceeded inside a closed room. This prevents odors and possible emission of pollutants. In addition, this way the pictured problems concerning the cold can be solved. In this case, extra costs must be taken into consideration. To estimate these costs, the study made by (Epstein, 2011) and the results given in Table 5 are used. It refers to a 25.000 tons indoor bio compost facility. Here, the operational costs (per year) have been estimated. Epstein calculates the proceeding costs to about 75 $\frac{€}{ton*year}$. This means that the use of a closed system with ventilation, the proceeding costs double in compare to the system that does not use such devices.

On the per person price, the following values occur:

$$costs_{proceeding\ costs} = 0{,}2\frac{kg}{day * PE} * 365\frac{day}{year} * \frac{1\ ton}{1000\ kg} * 75\frac{€}{ton}$$
$$= \mathbf{5,48}\frac{€}{\boldsymbol{year * PE}}$$

Now, the price for the pure composting and the further operational costs per PE have to be added.

$$Costs_{Composting} = price_{process} + price_{proceeding}$$
$$= 0{,}177\frac{€}{year * PE} + 5{,}5\frac{€}{year * PE} = \mathbf{5,65}\frac{€}{\boldsymbol{year * PE}}$$

When all this is applied, no concerns about the feasibility are to be expected. Still, the hygiene must be monitored much more than at the pyrolysis process in order to be ensured. Because of the use of indoor processing, the reliability and the limitation of odor emissions are increased to a good level.

4.5 Storing and collecting possibilities

4.5.1 Pull principle

When it comes to transporting any sort of waste to a central place where it can be treated or collected, the preferred method is the curbside system. The main idea here is that a company comes to the households, collects the waste and transports it to a central store or treatment plant. The prime example for a curbside system is the garbage collection. So, in order to estimate the costs for such a system, the existing garbage system with its costs can be consulted. Here, the main focus lais on the bio waste collection system since bio waste is the most similar waste to the fecal waste. In Hannover, the bio waste gets collected every 14 days. The price for this depends on the amount of bio waste. Therefore the amount of excrements has to be regarded. As mentioned in chapter 4.4, 0,2 kg/day are excreted. Now, referring to a density of 1,055 g/cm³ (Dr.agr.R.Mönicke, 1987), this leads to a volume of:

$$V_{\frac{fecal}{day}} = \frac{m_{\frac{fecal}{day}}}{\rho_{fecal}} = \frac{200\ g/day}{1{,}055\ g/mc^3} = 198{,}5\frac{cm^3}{day} = 0{,}1895\frac{l}{day}.$$

Thus, in 14 days, the following amount is created:

$$V_{fecal,14\,Days} = 0{,}189\,\frac{l}{day} * 14\,days = 2{,}65\,l$$

Table 6 only refers to bigger volumes, making it impossible to estimate the costs for such system accurately. Therefore, the calculations will now be made on a bigger scale. So, the volume of both scenarios will be applied. In this situation, a total collectable volume of excrements can be calculated:

$$Volume_{fecal,10\,000} = 0{,}189\,\frac{l}{day * person} * 200\,000\,person = \;3\,7800\,\frac{l}{day}$$
$$= 37{,}8\,\frac{m^3}{day}$$

$$Volume_{fecal,10\,000} = 0{,}189\,\frac{l}{day * person} * 10\,000\,person = \;1\,890\,\frac{l}{day} = 1{,}89\,\frac{m^3}{day}$$

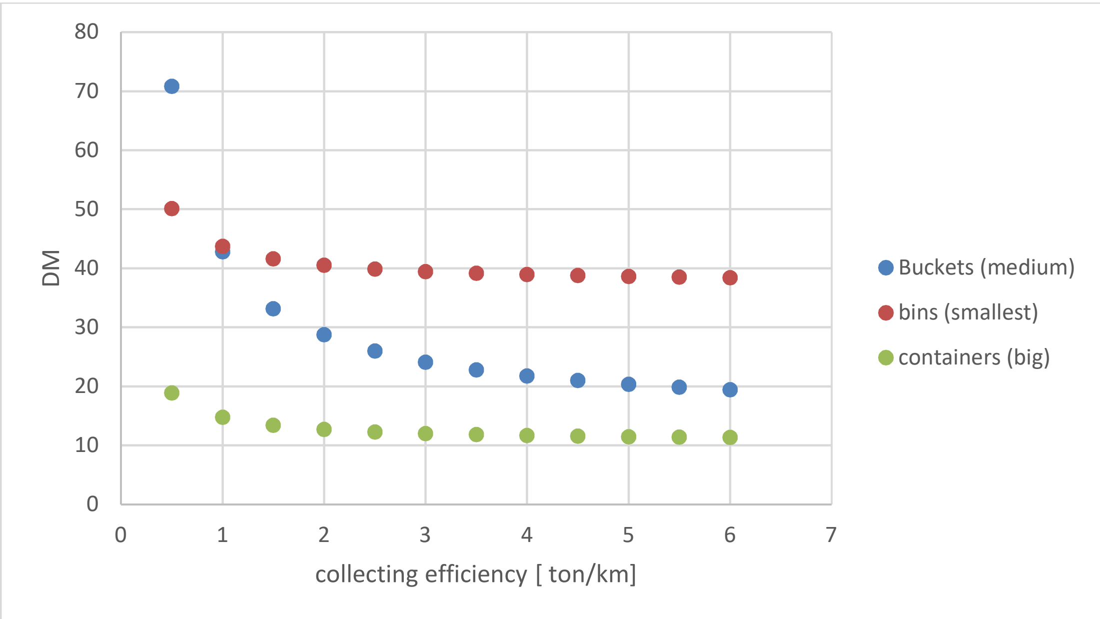

Figure 7 price calculation in relationship of the collecting density for different storage systems, values taken from (Strauf, 1974).

Figure 7 shows the relationship between the collecting density and the collecting price per ton. The collecting density signifies the amount of garbage a truck collects when driving one km. The price is given in DM (old currency of Germany). This is caused by the age of the information used for this graph. So, the concrete values are obsolete but the trend still has significance. It allows two logical conclusions. At first, the price drops logarithmically with increasing collecting density. This means in reverse, that with a low collecting density, the price increases rapidly. To estimate a typical collection density, values of the city Hannover will be applied. Hannover has 555.500 inhabitants (City of Hannover, 2017). The length of the road system in Hannover is about 1.300 km (city of Hannover, 2018). Bringing these figures into relation, in Hannover, the people/km ratio is about 427 inhabitants per km road. Every person defecates 0,2 kg per day. This leads to the collecting density of:

$$collecting\ density_{example:Hannover}$$
$$= 427\frac{inhabitants}{km_{road}} * 0{,}2\frac{\text{kg}}{\text{inhabitant} * \text{day}} = 85{,}4\frac{kg}{km * day}$$
$$= \mathbf{0,0854}\frac{\boldsymbol{ton}}{\boldsymbol{km * day}}$$

Figure 7 emphasises that the cost increase strongly when the collecting density is lower than 2 tons/km². To reach this value, the duration of a collection circle can be calculated:

$$duration_{collection} = \frac{2\frac{ton}{km}}{0{,}085\frac{ton}{km * day}} = 23{,}5\ days$$

So, when the demanded collection density should be reached, a collection has to be done about once a month in a highly populated city like Hannover and Tampere.

Because of a lack of data, an estimation of smaller cities is not done as trivial. Only possibility is estimating it by using the population density. Hannover has 555.553 inhabitants on an area of 204 km², which result to a density of 2723 inhabitant per km². It will now be assumed that the inhabitant density and the inhabitant per km value is linear to the size of a city. This assumption is made because usually, in smaller cities, single-family houses are a lot more common, in contrast to high-rise buildings in bigger cities. This decreases the density of people per km road strongly. For the following calculations, the city of Quakenbrück has been chosen since the values are given and the size is with 13 000 suitable as well (joint community artland, 2018). It follows with an inhabitant density of about 729 inhabitants/km²:

$$collecting\ density_{10\,000} = collection\ denity_{200\,000} * \frac{\text{inhabitant density}_{10\,000}}{inhabitant\ density_{200\,000}}$$
$$= \frac{427 inhbitants}{km} * \frac{729\frac{Inhabitants}{km^2}}{2723\frac{inhabitants}{km^2}} = \mathbf{114}\frac{\boldsymbol{inhabitants}}{\boldsymbol{km}}$$

The following calculations are analogue to those above:

$$collecting\ density_{10\ 000} = 114 \frac{inhabitants}{km_{road}} * 0{,}2 \frac{\text{kg}}{\text{inhabitant} * \text{day}} = 22{,}8 \frac{kg}{km * day} = 0{,}023 \frac{ton}{km * day}$$

$$duration_{collection} = \frac{2\frac{ton}{km}}{0{,}023\frac{ton}{km*day}} = 87{,}5\ days$$

To conclude, these calculations show that it is possible to do this collecting method. In bigger cities with a high population density it would be possible to have a collection once a month. In smaller cities, such collection is possible as well. Here, a collection every 3 month or less is advisable.

Figure 7 also shows that it is cheaper when using bigger storages where the collecting trucks can take the waste from. So, the most expensive system to pick up is using small tons. Using collecting places like containers where the waste from an area is summarized, costs only ¼ of the usage of waste bins.
Like mentioned before, the amounts of waste in the case of manures are minor. Figure 7 leads to the conclusion that it is more cost-efficient, when more waste can be collected at the same place. One possibility is to collect the excrements of more than one households. At the same time no energy should be consumed for the storing. This limits the applicability of maximizing the amount of waste.

Concerning the feasibility for such curbside systems, no greater challenges are expected, since similar systems for the normal household waste are established already. Nevertheless, a new system has to be developed due to possible odor emissions. Once developed, a similar workflow can be expected. Limitations in the feasibility are coming from strong seclusion, especially concerning the operational costs, which are expected to increase strongly like Figure 7 emphasizes.

The costs are dependent on the garbage density as well as the possible to gather together the manure of more households. If it is possible to establish one storage for many households, the prices can be very low. In contrast, if only one secluded household can be collected, the prices can increase strongly. To have an estimation, the prices for the collection of bio waste can be consulted. Here, the highest price per kilo occurs when using the smallest container, like pictured in Table 4. The price calculation is exercised for the most expensive case:

$$Price_{trasnport} = \frac{Price}{mass_{produced}} * mass_{produced} = 1{,}473 \frac{€}{kg} * 0{,}2 \frac{kg}{day} * 365 \frac{day}{year}$$

$$= \mathbf{107,5} \frac{€}{\boldsymbol{Year * Person}}$$

A collecting system would likely be more complex than the one for normal bio waste because the manure will probably be stored in a closed tank to prevent odors.

Concerning the sustainability, this system is neither good or bad. So, it would increase the traffic, with several consequences, even though only a couple of trucks will be needed. Still, this increase of traffic, that will probably lead to a negative public reaction.

4.5.2 Transportation using existing pipelines

One possibility would be the use of already existing pipeline systems which is currently used for the transportation of the human waste. The bio waste could be transported via the pipelines. The current system does not have the need any sort of energy since gravity can be used. Here, problems will likely occur since the gravity presumably is not enough for transporting the feces. Since the new system will not use water to dilute the fecal matter, it is unlikely that this transportation system will work in this appliance.
So, the feasibility is not given in this case which makes a further investigation unnecessary.

Another possibility of using the pipeline system is using it as a storage. The toilets are connected with the system already. This suggests itself to use this connection as well as the pipeline system. It is conceivable to adjust the system structurally, so the feces can be stored underground and the urine, since it has low viscosity, could still be transported via gravity to a centralized store. It is also possible that with this system, feces from more than one house could be collected together. This way, referring to the cost behavior pictured in Figure 7, the transportation could be minimized.

If this idea is feasible or not, cannot be investigated in the frame of this thesis. Here, widespread investigations are necessary to make a clear predication. Because the gathering of the manures from multiple households is probably not suitable for single-family houses it is questionable if this concept is suitable in smaller cities. In higher houses, the gravity could easily transport the manures from every flat of the house into bigger containers, as happened in the Sweden-China Erdos Eco-Town project. In smaller cities with single-family households, creating such collecting system while using no energy (besides gravity) seems very unlikely possible.

Concerning the costs, Figure 7 shows a chance of saving money by gathering waste as much as possible. The use of containers decreases the costs by 75% in relation to using smaller bins. Taking this relation, the price in bigger cities could potentially decrease to:

$$price = 107{,}5\,\frac{€}{year * PE} * \frac{1}{4} = 26{,}88\,\frac{€}{year * PE}$$

Since this is an appliance of the pull principle, the sustainability is as good as mentioned before.

There are big fortunes concerning the public reaction, since people will only change their behavior in a slight way. Thus, they will have to use the dry toilets but the home remodeling as well as the other structural alteration works not sever. Also, this system will increase the effort for the waste disposal.

4.5.3 Push principle

The push principle (also known as bring system) means that the producer of waste brings the waste by himself to a centralized place. In which cases and for which distances this system is applied basically depends on the amount of the respective waste. A frequently used example are batteries. These do not belong in the normal waste and must be treated separately. Here, there are specific places and stores where the batteries can be disposed legally. The principle is applied when the amounts of waste is so low that it would not be lucrative enough to establish a pull principle (Cord-Landwehr, 2002).

Applying the system in this case is generally possible. In this scenario, everyone would collect his own manure and urine separately. Then, the manure would be brought to centralized stores. In which frequency and how big the stores are could depend on the area and the size and possibilities for every household. The transportation likely must be done with cars and, in addition, special features like a special trailer. So, the feasibility is given but very limited for people that do not have good financial backgrounds, who cannot afford enough for buying named items.
The operational costs with this principle are very high. As explained, the transport will likely have to be applied by car. So, everyone has to drive to the central stores and load the manure and urine there. Here, the costs depend on how far people have to drive to the stores and on what car they are using. But it is certain that these costs will be much higher than the one for a pull principle. Only exception could occur in very low populated areas, where a pull system would be extremely costly.
Also, the sustainability is worse, compared to the pull principle since many cars, that drive separately have much higher pollutant emission than one truck. In addition, much traffic around the stores will increase time and pollution even more.
Due to the mentioned effects, the public respond will very like not be very fortunate. People lose a lot of time and money. So, it is not expectable that the public would accept an implementation of this concept.

4.6 **Further influential factors**

A changed system would affect many fields. and the change of the related costs is difficult to estimate. Assessing these additional cost-effects were not a core scope of this work, however some affected factors need to be considered.

4.6.1 Water cost

Once the toilets are working without the use of water, the overall household water consumption decreases for about 20%. In theory, this could lead to a decrease of the costs of fresh water of 20 % as well, since the demand decreases while the offer could stay the same (Alison Wood, 2015). In practice, a decrease of the price by 20 % is not realistic. The main reason will lay in the supply of the fresh water. Drinking water is produced in special water treatment plants. These plants are designed for certain mass flows. If the water consumption decreases, these plants will have to be run in turndowns which decreases the efficiency. This would again lead to higher operational costs.

Figure 5 clearly shows a linear trend for the price of fresh water over the years 1995 to 2017. The price index starts 1995 with a value of 74,6 and ends 2017 with 111,2 points. So, the costs increased in 22 years for about 50%. Unfortunately, it is not further described if this index refers to the price per volume or the overall price of the whole country.
Figure 6 shows the consumption per person over the same lapse of time.
The consumption in 1990 started with 147 l/day and decreased exponentially to about 121 l/day (first reached in year 2010), decreasing of about 18%. After 2010 the consumption seems to stay stable at this level.

Regarding Figure 6 and Figure 7 it gets clear, that the price for the fresh water increases, even though the consumption decreases. To clarify the relationship between costs and consumption of fresh water, these figures are combined in Figure 8.

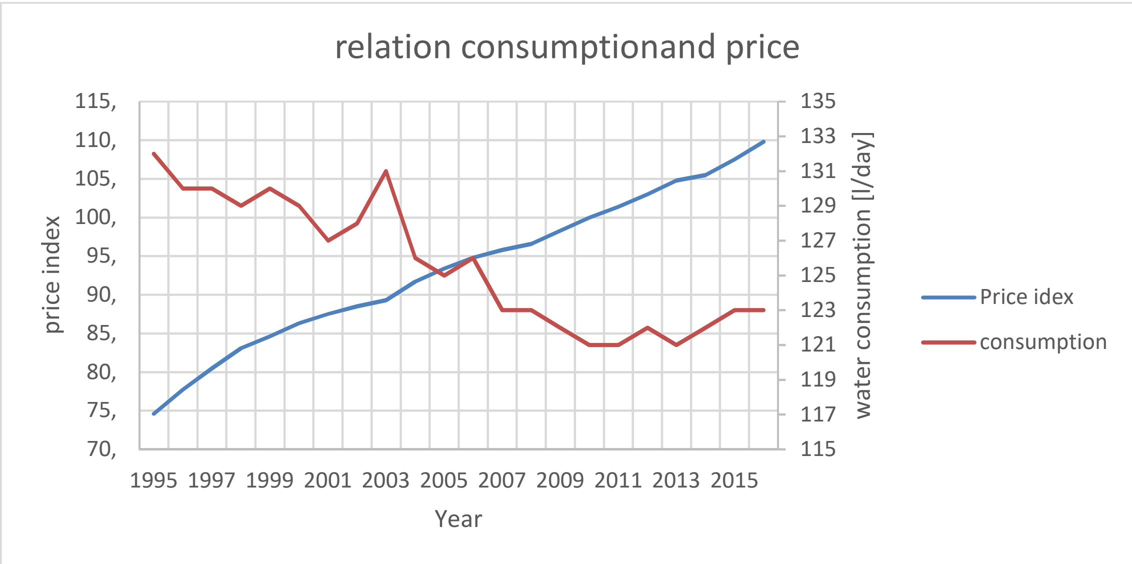

Figure 8 relationship between the consumption of water (abscissa) and the price (ordinate)

These figures and especially the Figure 8 do not show any kind of clear relationship between the consumption and the price of fresh water. This assumption is especially clear, when regarding noticeable years like those around 2003. Here, the consumption went up strongly and afterwards felt down again rapidly. Still the price index only shows a little sharp bend. This underlines, that making an estimation about how the price of fresh water will be affected by using other toilet systems is not trivially done.

4.6.2 Impact on infrastructure

Another possible negative effect of the non-water using system is a result of the transportation. Beside the direct costs like fuel, personal etc., there are also cost called external diseconomies. These are costs, that result out of several actions which are not classifiable clearly to one causer. One prime example is traffic. Traffic can affect the health and the sleep of people living close to frequently used roads. These sicknesses or shorts of sleep lead to a decrease of the effectivity of the employee. In addition, traffic jams can lead to delays in processes of manufacturing companies. In addition, a higher traffic can lead to a lower reputation of the company (Herbert Baum, 2010).
A related case was in Hannover in the last quartal of 2017. The energy supplier "Enercity" published a plan that they wanted to install a sewage sludge pyrolysis plant. The public reacted worried concerning additional traffic.
The government usually pays these external diseconomies. Still the awareness that these costs will increase in any case have to be given, even though an estimation of the amount of cost is not possible (Conrad von Meding, 2017).
Other costs which could result out of additional traffic is the risk of accidents. Here, two sorts of costs result. On one hand, the trucks can be damaged and need repair or have to be replaced. On the other hand, the delivered materials can be spread over the street, environment etc. Besides, the loss of the material, costs for the cleaning will result as well. In 2005 12.382 accidents have been reported by the landscaping professional association (Herbert Baum, 2010).

4.6.3 Impacts on waste water treatment plant

Current waste water treatment plants are designed for their specific task. A change of the influent will lead a change in the function of the whole system. Without human excrement, the bacteria in the biological part of the waste water treatment will not have enough nutrients. This lack of nutrients will lead to a dysfunction of the treatment process. Now, two possibilities are conceivable. First, nutrients could be added. To do so, properly extra fields must be cultivated, that create plants which bring the necessary nutrients for the

plants. The costs that result out of this depend on amount and plants that are necessary for this. The other possibility is a change in the whole waste water treatment plant system. So, the lack of human waste in the waste water changes the whole structure of the waste water. This sort of water (waste water without fecal matter) is oftentimes called grey-water. This greywater can be treated easily with several forms of filtration. The most common ones are sand and gravel filters as well as bio-filters.
These filtrations are a cheap and easy way to clean grey water, that is not polluted heavily. Oftentimes it works exclusively by gravitation (Huhn, 2015). Problems occur when regarding bigger cities. Here, it is questionable if the amounts of greywater which will result can be filtrated on such easy way, or if methods with a higher technical effort are needed.

4.7 Overview and SWOT analysis

The following table is a compilation of the gained acknowledges concerning the price of each waste water treatment methods.

Table 8 Overview of all the costs

All prices are in €/PE*Year.	**Composting**	**Pyrolysing**	**Waste water treatment plants**
Process	5,65 €	10,12 €	65,31 €
Transportation (gathering)	26,88 €	26,88 €	1,79 €
Transportation (no gathering)	107,5 €	107,5 €	1,79 €
Overall price (without gathering)	113,15 €	117,62 €	67,1 €
Overall price (with gathering)	32,53 €	37 €	67,1 €
Possibility of regain money	No (product likely will not have a good quality)	Yes	Yes, but before, sewage sludge has to be pyrolysed.
Dry toilets applicable?	Yes	Yes	No
Phosphorus recoupment?	Yes	Yes	fragmentary

This table shows that the transportation is the most important figure in the alternative treatment methods. It shows that it is possible to run both alternative processes can be operated with lower costs than the waste water treatment plants. This is only possible if gathering is applicable. In general, the cheapest process is the composting process. The waste water treatment plants have advantages regarding the transportation. The price here is, in contrast to the alternatives, very low. Differences occur concerning the possibilities of regaining money. The best possibility is the pyrolyzing. Here the product can be sold either as an energy deliverer (coal) or as a fertilizer. Studies have shown that the pyrolyzing process can be operated as a money gaining process (Epstein, 2011). The composting process is likely not going to have a saleable product. It is more likely that the product will be given to farmers or other people for free like it is proceeded with composted sewage sludge nowadays. This leads to the waste water treatment plants. Some plants treat their dried sewage sludge to gain biochar (city of Hannover, 2016). Therefore, the sewage sludge gets pyrolyzed. So, two of the invested processes are operated one after another, leading to an increased price and infrastructure.

Saving water while using waste water treatment plants is limited because the water is needed for the dilution of the feces as well as in the process, while the other processes are operated without the need of allowance of water.

Referring the regain of the phosphorus, the composting process is the best alternative. This is mainly based on the possibility of using the biochar of the pyrolyzing process as an energy deliverer. This may lead to the behavior, that the people are using the coal not as a fertilizer since using it to gain energy is more economical. The waste water treatment plants are improving on that field but still not all the phosphorus is regained here.

Now, the SWOT analysis is applied:

The major strength of the new system is that the main goals can be accomplished. About 20% of the water consumption can be saved and the nutrients out of human excrements can be regained as well. Another good aspect is the simplicity of the processes. After some measures, like the sorting of containments, both process can run easier than the waste water treatment plants, where several different processes have to be applied.

The thesis showed the price can be a major issue. Both processes have higher operational costs than the traditional treatment system. These higher costs especially refer to the transportation. Here, the traditional system has the advantage, that the transportation costs are, due to the dilution and the use of gravity, very small. Another problem is the direction of

the technic. So, it either possible to try to change the system to separated treatment methods or to further develop the existing technic, meaning to increase waste water treatment plants. It occurs that the second way is followed more since many new treatment plants are build up nowadays. One reason for that is that a change of the systems would require a lot of effort and money.
This weak spot leaves a great chance for the new system. Many developing countries do not have an established waste water system. In addition, in many of these countries, water shortage is a problem which makes a system like it is in Europe for instance, very unlikely to be acceptable. In these countries, a no-water-using system might be the only applicable alternative. Nevertheless, the new system can always bring the chance of gain money from the product. This money can come either from gained fertilizer, that can be sold or from gaining energy.
There are also some threads that could occur if the system is changed. The major one is that the public does not accept the system. The new system demands a change in the behavior of people (containments have to be avoided). Also, much construction work and a increased load of the infrastructure will likely result.

So, to conclude finally, changing the system can be profitable because of the named strengths. Nevertheless, it is a project that can only work if the public accepts and wants such change.

4.8 **Final conclusion**

This dissertation estimates operational costs of composting and pyrolysis of and compare these with the real operational costs of waste water treatment plants. Thus, it shows that the alternative processes are with between 5 and 10 euros per ton rather low in comparison to the costs for transportation. The transport costs can account for more than 90% of the total price. Thus, it is necessary to optimize these costs. It is possible to increase the transportation costs by agglomerating the waste of more than one household, which is likely only possible in bigger cities with higher population density. The need of transportation is given for pyrolyzing but not necessarily for composting since here, single household applications are possible. This leads to the chance especially for secluded villages. On the other hand, pyrolyzing is not well applicable in secluded areas. This is mainly because the process needs to be run all the time. This leads to the conclusion that composting is the better in lowly populated areas while pyrolyzing has advantages in bigger cities. The boundaries are fluid here but de to the fact that pyrolyzing creates a saleable product, the process is likely to be preferred if possible.

Generally, the thesis shows that using alternative fecal treatment methods are able to save water and regain phosphorus but the operational costs are very likely going to be much higher than the current system, especially taken into consideration that this thesis only regarded the treatment for fecal treatment and disregarded the urine.

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